Compositional Processes from an Ecological Perspective

Damián Keller

ABSTRACT

The author discusses the conceptual basis of an ecological approach to music composition, considering the epistemological and compositional concepts involved. The author's text-and-tape piece, *touch'n'go/toco y me voy*, is presented as an example of an ecologically based musical work, in which the sound event functions as the basic unit of multilevel musical structures. Digital resynthesis techniques are integrated in the compositional process by means of environmental sound models. Ecological models establish formal relationships without obscuring the recognizability of everyday sounds. Materials, techniques, perceptual constraints and references to social issues are integrated in a consistent compositional method.

CONCEPTUAL BASIS AND HISTORICAL BACKGROUND

The ecological approach to music composition integrates models of environmental sound classes with social and cultural elements that contextualize a musical work. Epistemologically, this approach treats compositional activity as a dynamic process, in which materials determine techniques, and techniques enhance the available sound palette. The sounds used and the formal processes that define a piece are in a state of constant flux. This method can be compared to the dynamics of individual-environment interaction [1], which both constrain the way we perceive music and environmental sounds [2] and lead us to develop forms of sonic organization that are directly related to our everyday life.

Computer-based compositional work, as originally proposed by L.A. Hiller and L.M. Isaacson [3], Iannis Xenakis [4] and other composers, provides the technical basis for integrating sound models with existing compositional tools. Xenakis laid out an approach to composition that let one equate sonic elements to data structures and the transformation of material to the use of algorithmic functions. Thus, Xenakis described composing as a three-stage process: (1) First, define variables; (2) Then parse the time axis to establish a temporal structure for the piece; (3) Finally, compose, by implementing functions that control the relationship between sonic variables and temporal structures.

Although this schematic of composition is generally valid, the development of computer and electroacoustic music during the second half of the twentieth century has shown that sonic parameters cannot exist in a formal space devoid of context. Listening processes are constrained by their temporal and spectral resolution. Our hearing system parses or groups sound elements to form higher-level percepts such as streams and textures [5,6] in a context-dependent manner.

In fact, music listening is deeply influenced by the individual's cultural background and by the music's social function within a specific community [7]. In addition, music and sound-making influence the way listeners relate to their environment and perceive their sonic world. Taking these observations one step further, J. Attali [8] suggests that music and sound not only modify the environment, but also shape social dynamics.

From a compositional standpoint, the relationship between music and environment has been extensively explored by a group of soundscape composers in Vancouver [9–11]. As stated by B. Truax [12], soundscape composition involves (1) the listener's recognition of the source material; (2) the listener's experience of the material to complete the music's network of meanings; (3) the composer's knowledge of the material as a way of shaping the composition; and finally (4) the enhancement and transformation of our worldview and perceptual habits.

Soundscape studies indicate that music-making is constrained by its social context even as it reshapes that context. Regarding the importance of listener-environment interaction, this view relates closely to the ecological approach. Ecological psychology suggests that a mutual-determination process dictates how we perceive our environment—this process cannot be parsed into arbitrary time-slices but needs to be understood as a configuration of environmentally meaningful events. For this reason, in the following section I discuss two concepts taken from ecological psychology that are instrumental in composition with everyday sound: individual-environment interaction and finite time events.

PERCEPTION AND ENVIRONMENT

Although the ecological approach to psychology was first proposed in the 1960s by J.J. Gibson [13], it took 20 years for researchers in auditory perception to embrace it. The last 15 years have shown an increase in the number of studies grounded in this perspective [14,15]. Even the predominant information processing paradigm has adopted methods and ideas stemming from the ecological framework [16].

From a Gibsonian perspective, information is structure that specifies an environment to an animal. This structure inheres in higher-order organization occurring over time [17]. As the animal gathers information from the environment, it effects changes on its surroundings. As the animal's perception is progressively "tuned" to the characteristics of the environment, it increases its chances of survival.

Current research on perception of environmental sounds highlights epistemological issues that need to be considered when composing with mundane sounds. From an ecological perspective, a system cannot be studied in isolated parts. Events actually occurring in the environment define ecological validity. Thus, ecological models should be constrained to eco-

Damián Keller (composer), 62H Abrams Court, EV, Stanford University, CA 94305, U.S.A. E-mail: <dkeller@sfu.ca>.

logically feasible parameter ranges and should take into account the interaction between an active individual and an ever-changing environment, which determines a process of pattern formation.

C.F. Michaels and C. Carello argue that time is directly related to the informational structure of the stimulus:

> Time is not chopped into an arbitrary succession of nows, but is organized into naturally occurring events of varying duration. . . . If time is viewed as an abstraction from change we might as well question the value of that abstraction. After all, change itself (events in space-time) is of interest to a behaving animal, not absolute time. . . . The notion of absolute time is given up in favor of space-time on the belief that perceivers do not perceive space and time, but events in space-time [18].

Against the assumption of absolute time as separate from actually occurring events, I have developed compositional models that parse time into event-dependent chunks [19]. This creates a system that is reconfigured whenever it finds new information. Change acquires a new meaning: it is not simply the fluctuation of variables; it dictates how these variables are observed. That is, the significant unit of observation is the event defined by ecologically meaningful boundaries. As we will see below in the section on compositional methods, the concept of the event in ecologically based composition has a direct impact on the organization of temporal layers and on pattern-formation processes.

Musical Structure versus Everyday Sound?

From the discussion above we can infer that a musical work is shaped by the perceptual processes involved in listening, though at the same time it modifies the individual's perception of music and environment. Therefore, a useful representation of musical structure has to tackle both perceptual and social issues.

Compositional processes involve several levels of organization. Parsing the sound material at the level of the note is not appropriate for the complex micro- and meso-structure of everyday sound. At the other extreme, independent parameters such as frequency (within the context of Fourier-based models) or arbitrary amplitude envelopes do not engender perceptually meaningful transformations. The concept of the ecologically feasible event is necessary both from an epistemological and a practical point of view. For composers concerned with sonic structure, their material shapes the techniques they use and these techniques serve as tools to generate new material.

Traditional music theory chooses to work with a unit that maps easily onto Western music notation, i.e. the note. Unfortunately, sound organization by means of algorithmic tools, or perceptual processes triggered by musical stimuli, do not necessarily correspond to discrete, invariant signs on a musical staff. Models that use spectral and micro-temporal information [20] can be organized in units that map onto higher levels of musical structure. This approach could eventually lead to a more flexible representation of musical sound models.

Composers concerned with perceptual issues, such as T. Murail and G. Grisey, have written and experimented with various spectral and temporal configurations, applying spectral models both to instrumental writing and electronic sound. The use of consistent strategies to organize spectral material and macro-temporal structures addresses a key problem in late twentieth-century composition, namely, the lack of meaningful units to manipulate musical structures.

Authors in related fields have embraced the idea that a dissection of complex auditory stimuli qualitatively changes the underlying perceptual processes [21,22]. Thus, various alternatives have been devised to overcome the limitations of atomistic approaches. Broadly speaking, they are: (1) experimental aesthetics, which studies the social factors governing aesthetic trends [23]; (2) acoustic communication, which concentrates on the compositional use of environmental sound within specific cultural contexts [24]; (3) cognitive approaches that study perception from a functional and information-based perspective [25]; and (4) ecological acoustics, which focuses on auditory perception within a Gibsonian paradigm [26].

Cultural context and social dynamics are a rich source of data for music models. Linking an acoustic sound structure to the music pattern-formation processes within a given cultural context offers a broader perspective than that provided by traditional music theory. In this light, the assumption of a "universal musical language," implicit in most cogni-

Fig. 1. ***touch'n'go/toco y me voy,*** **text-and-tape piece published as an enhanced CD, 1999. (Graphic design: Tanya Petreman. Photo: Andrew Czink. © earsay productions.)**

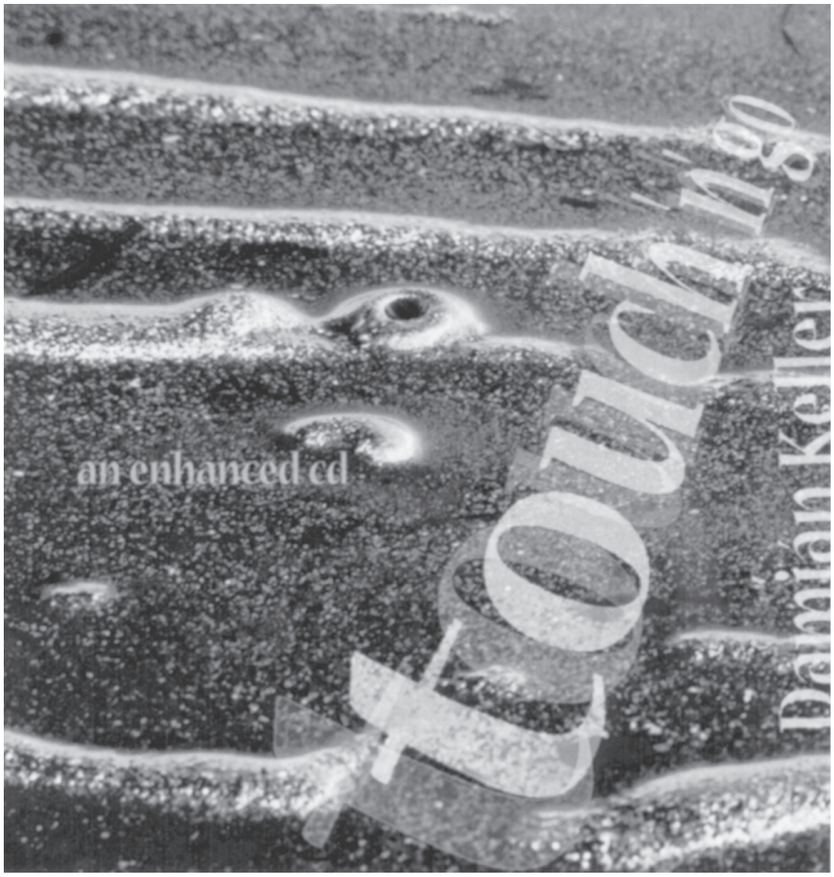


Table 1. *touch'n'go/toco y me voy* consists of 11 sections, which can be freely explored by the reader/listener.

Section	English title	Spanish title	CD tracks
1	Pandemonium	Pandemonio	1,8,14
2	Realpolitik	En Vías de Desarrollo	2
3	Action to Be Taken	¡Qué Quemo!	3
4	Farewell, Welfare	La Partida	4
5	Let Me See . . . How Can I Word It?	Palabras	5,7
6	Least, but not Last	Todo Pasa	6
7	A Waltz in a Ball	Como Bola sin Manija	9
8	sCRATch	El Escrache	10
9	Coin a Name	(Me) Río de la Plata	11
10	Spill, Spiel, Spoil	No al Derramamiento	12
11	Vox Populi	Vox Populi	13

tive literature on music [27], can only be grounded in a nineteenth-century aesthetic perspective. I propose, however, that the processes involved in our perception of sound structure can be applied to musical composition with environmental sounds as well. In other words, models of musical structure should also deal with sources outside the instrumental palette. From an ecological perspective, this implies a shift in focus from abstract representations to sound structures constrained by the interaction of the individual with the environment. To implement this epistemological turn, concepts such as individual-environment co-determination, pattern-formation process, finite time event and ecological validity need to be incorporated into our day-to-day compositional activity.

The following section focuses on the impact of ecological concepts on the compositional techniques I used to create my text-and-tape piece *touch'n'go/toco y me voy*. First, I explain how ecological models extend the palette of sound resynthesis and transformational methods in composition. Then I explore further the concept of the ecologically feasible sound event. A discussion of source placement and spatial consistency rounds out the section.

COMPOSITIONAL PROCESSES IN *TOUCH'N'GO/TOCO Y ME VOY*

touch'n'go/toco y me voy (1998–1999) is a piece for eight-channel computer-generated tape and hypertext. Depending on the venue, *touch'n'go* has been played as a tape solo piece with an eight-speaker diffusion system, as a stereo piece with hypertext markup language (HTML) and as a live performance work for actor and tape. In its live version, the text can be interpreted by one bilingual actor or by two actors who share the Spanish and English texts. As a WWW page, it can be explored through its hypertext links (Fig. 1).

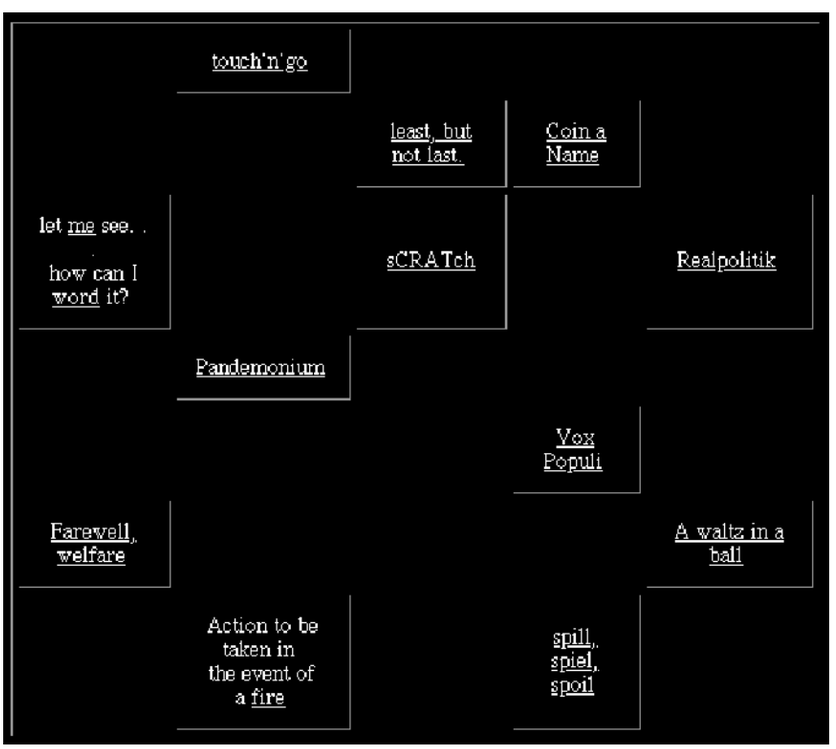
I chose the enhanced CD format for the commercial release of *touch'n'go* based on the formal layout of the piece. *Touch'n'go* can be heard as a linearly composed piece, or it can be explored through randomly chosen paths. The piece comprises 11 self-contained sections, each of which stand as independent compositions. The CD is divided into 14 tracks. Each track corresponds to one section, with the exceptions of *Pandemonium*—separated into three tracks—and *Let Me See . . . How Can I Word It?,* which has two parts (see Table 1). Its structure is based on Jorge Luis Borges's [28] 1956 short story *The Garden of the Forking Paths.* In this story, Borges describes a Japanese garden in which the visitor must choose among several paths at each bifurcation. The road chosen becomes the traveler's reality, and all other potential futures are lost.

This idea is not explicitly explored in any section of *touch'n'go* but permeates the structure of the music and the text. The form of the piece is created as the listener/reader "walks" through its sections. The path can be laid out by using the shuffle mode on a CD player or it can be set by the user while listening to the tracks.

Text

In each musical section of *touch'n'go,* short literary texts complement or develop the ideas presented in the music (Fig. 2). This format can be seen as an extension of the traditional program notes. Nevertheless, the hypertext presentation opens up a more complex interlocking of meanings. For example, the words chosen as hypertext links suggest a specific relationship with the text to which they lead. Similarly, the unfolding of text establishes a dynamic form of poetry that is hard to attain on plain paper (e.g. *Coin a Name, sCRATch).* Most importantly, the exploration of the text becomes a time-based process similar in form and dynamics to the form-creation process one realizes by listening to the piece.

Fig. 2. There are texts in English and Spanish for each section of *touch'n'go/toco y me voy*, 1999. Texts are formatted in HTML.



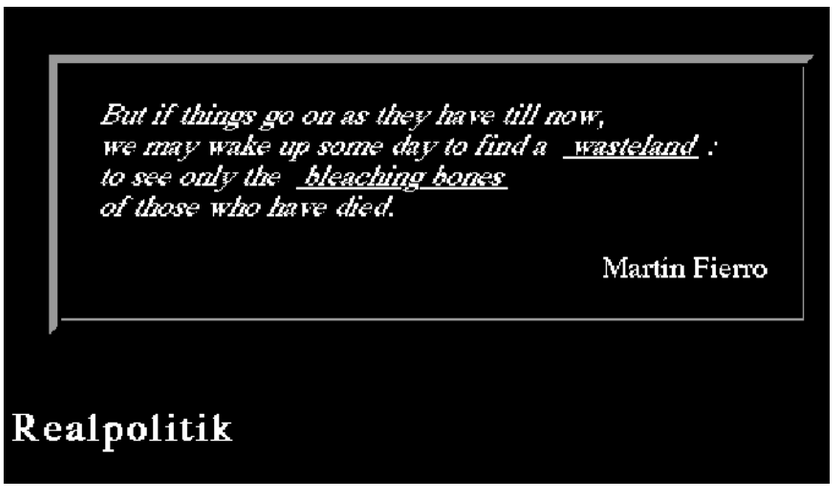


Fig. 3. ***touch'n'go/toco y me voy*** **explores political and cultural references through its thematic axis and choice of texts, 1999.**

The cross-cultural references in the piece as well as the impossibility of a literal translation of poetic material led me to write different texts in English and Spanish. As demonstrated by masterpieces of translation, the best way to adapt a text to another language is to rewrite it. But this is not feasible for well-known works such as José Hernández's *Martín Fierro*, or Borges's and Cortázar's texts [29,30]. Therefore, I organized a working team of English and Spanish speakers, including a certified translator, Ivan Roksandic, and myself to attempt a close transcription of meaning and feel for these texts. I wrote the remaining material in either English or Spanish, without attempting a literal translation. The same procedure was used for the title of every section (see Table 1).

Each title suggests ambivalent meanings and hints at political and social issues within either a North American or Latin American context. Explicit political references are explored in *Coin a Name ([Me] Río de la Plata)*, *Realpolitik (En Vías de Desarrollo)* and *sCRATch (El Escrache)*. Moreover, both the thematic axis and the choice of texts imply a social commentary and a firm cultural grounding (Fig. 3). José Hernández's *Martín Fierro* is the epic poem that gave birth to the tradition of socially engaged Argentinean literature. The main character of the book, the outcast wanderer gaucho, is symbolically taken up in *touch'n'go*. Thus, the piece could be understood as the possible worlds visited by a gaucho or a traveler. *Coin a Name* draws a parallel between the action of throwing coins in a river and the murders committed by the most recent military dictatorship in Argentina. One of the *modus operandi* of the military killers was to throw their victims alive into the river from helicopters. Presently, human rights organizations are denouncing these and other crimes by doing public demonstrations called *escraches*. *Escrachar* means to put in evidence, to unveil someone who tries to hide his true identity [31]. Many individuals who committed crimes against humanity are still free. Some of them occupy positions of political power and continue their illegal practices. The objective of the *escraches* is to make their names and addresses known to the communities in which these people live. *Realpolitik* was inspired by the bombing of Baghdad. During the realization of *touch'n'go,* reality caught up with art as Belgrade, Yugoslavia, another ancient and culturally rich city, was destroyed by bombs.

Sound

Ecologically based composition integrates representations of environmental sound classes with social and cultural references. Sound models are constrained to perceptually recognizable parameter ranges. In this context, formal issues take a quite specific meaning. Form is a dynamic process taking place at the micro, meso and macro levels. When properties not explicitly determined by specific parameters emerge at different levels, we witness a pattern-formation process [32]. In this case, form is not defined by the algorithmic parameters of the piece but results from the interaction among its sonic elements. In a general sense, pattern-formation refers to the emergence of higher-level forms or behaviors resulting from the interaction of two or more systems. F.J. Varela and his colleagues [33] have used the term "pattern formation" to describe the mutual adaptation processes taking place between the individual and the environment.

From the ecological perspective, the formal structure that serves as a vehicle for communication seamlessly integrates references to the cultural environments of both the listener and the piece. This compositional approach does not imply any judgment on the value of abstract music; I am simply acknowledging the impossibility of listening to music in a cultural vacuum.

Furthermore, the sound classes my work utilizes as source material constrain the transformational processes employed. The relevance of everyday sounds as compositional raw material derives from their acoustic richness and their direct reference to the listener's environment. Ecological models provide a framework that extends the use of mundane sounds to formally and perceptually consistent domains, i.e. the sound classes can be compositionally shaped without losing their perceptually relevant characteristics. Once a sound model is defined, a range of behaviors can be explored. Because ecologically based sound classes can be easily recognized, paradoxical and extended sonic transformations can be integrated into the compositional discourse. These techniques are explored in *Coin a Name*, where the sound of splashing water is smoothly turned into splashing glass—that is, glass impacts that resemble the meso-temporal behavior of splashing water. Similarly, in *Action to Be Taken in the Event of Fire*, the sounds of matches being lit are used to excite string resonators, creating the effect of stringed instruments being played by fire.

The musical material of *touch'n'go* is the result of dynamic processes both at the meso and macro levels. Two structural processes are exploited in this piece: (1) the emergence of macro-structural properties by interactions among lower-level elements and (2) isomorphism. *Farewell, Welfare* provides an example of isomorphic processes at conceptual, algorithmic and perceptual levels. The section develops Zeno's idea of an infinite labyrinth [34]. This labyrinth consists of a straight line that one travels recursively by covering half its length with each movement. Obviously, the end of the line can never be reached. The algorithm I used for producing all sounds in this 2-minute section is a variation of the Karplus-Strong

[35] string model and uses a single short sample as source material. This sample is "walked" by two pointers at different rates, producing an ever-rising or ever-falling sound, depending on the parameters input to the model. These parameters are randomly generated within dynamically changing ranges. The sound produced is akin to a combination of Shepard tones with self-similar events that occur at ever-expanding time spans. Although *Farewell, Welfare* does not make use of everyday sound models, it explores a sound space generated by a synthetic instrument consistently with the methods employed in other sections. Specifically, sound results from the interaction of an excitation process with a resonant system. Here the system does not represent a real-world model, but its behavior produces a sonic result consistent with the concept and the algorithmic structure of the piece.

The model I developed for *Vox Populi* uses a small pool of conch shell sound samples. These samples have a harmonic spectrum with some noise content. When combined randomly, they approximate the behavior of choir-like formants [36]. These formants result from the interaction of the samples at a meso level. Thus, the effect at the macro level is qualitatively different from the characteristics of the source sounds.

A similar phenomenon can be observed in the "structured rain" material in *least, but not last*, which makes use of a three-stage process to generate this sound. First, I produced several types of drop sounds using convolution. Convolution consists of applying the spectral dynamics of a source sound to those of a target sound [37]. I then organized the drops as constrained random meso-level events. Finally, I distributed the meso events in a slightly irregular rhythmic pattern by employing a slowly evolving dynamic process. The result was a sound that resembled wind and rain with metallic reverberations in the background. *Least, but not last* makes use of two contrasting spaces—metaphorically speaking, the space of the living and the space of the dead. I produced the first space by mixing a recording of a big, open building; the enclosed space was created through convolution of granular samples.

The sound event as a basic musical unit is the driving principle of the synthesis and organization of material in *touch'n'go*. No sound in this piece includes an ecologically impossible attack or decay. Excitations arise from using grains extracted from real-world sounds: water drops, cracking wood, glass hitting glass, etc. The key contribution of the ecological models to this piece is the organization of spectrally complex samples into feasible meso-temporal patterns. Furthermore, the consistency among meso and macro levels unveils new properties resulting from the interaction of these levels. For example, the rising pitch produced by two bottles bouncing against each other results from amplitude modulation of the accelerating, resonant glass impacts [38]. Likewise, the wind-like sound of high-density water-drop textures is produced by the overlap of granular decays, which are heard as slowly varying formants [39]. As used here, the method is somewhat similar to formant wave function (FOF) synthesis [40].

At the basis of the ecological models I use lies a set of constrained random algorithms that generate constantly varying parameters within predetermined ranges. The constraints applied approximate the range of variation in environmental sound classes. I obtained ranges of parameter variation by synthesizing hundreds of instances of each sound model and comparing the aural results to various examples of recorded sounds. I further tested the recognizability of resynthesized sounds through an informal listening sessions with both musicians and non-musicians.

Ecological models produce statistically constrained sound classes instead of a single deterministic sound. As simplistic as it may seem, this is what allows algorithmic models to simulate the behavior of ever-changing environmental sonic worlds. No sound in the environment exists twice in the same configuration. Therefore, no sound in an ecologically based piece should be literally repeated. By the same token, each realization of the piece is unique in its micro- and meso-level characteristics [41].

In *touch'n'go*, all sounds "live" in feasible spaces. I used two methods for placing events within a virtual acoustic field: convolution of granular samples and control of phase synchronicity among granular streams [42]. A convolution-designed grain consists of an ecologically meaningful short sound, such as a water drop or a bubble, which is convolved with the impulse response of a cavern or any other reverberant space. When distributing these grains as meso-level time patterns, the result is a stream of events that occurs within the space defined by the impulse response used; for example, bubbles inside a cavern. Given that I could use several types of grain, the number of simultaneous spaces created depended on the limits of our auditory system in discriminating sounds coming from different reverberant spaces. The other method I utilized for virtual sound placement is phase-controlled granulation. This type of processing increases the volume of the source sound, as defined by Truax [43], by superimposing several granulated versions of the processed sound. If the phase-delay among these streams is kept constant, the effect is akin to the reflections produced by a reverberant space. The number of "reflections" is roughly proportional to the number of streams. The "structured rain" in *least, but not last* was produced using these techniques.

Ecological consistency guided my organization of the eight-channel diffusion of the piece. I used Harmonic Functions' DM8 computer-controlled diffusion system [44]. Actions that suggest movement, such as breaking, rolling or scraping, were diffused through dynamically changing patterns. I gave environmental background sounds produced by static sources—e.g. water and distant horns—wide diffusion settings and very little or no movement. I treated the human voice as a single source by placing it on a stereo field. The circular speaker layout allowed me to explore a variety of sound trajectories: front-to-back, back-to-front, diagonal and side-to-side movement. This disposition disrupted the hierarchy of front as the only important reference and kept the audience constantly surrounded by consistently placed sources.

CONCLUSION

Ecologically based composition makes use of everyday sound models that are constrained to perceptually meaningful parameter ranges. Complementarily, it provides references to the social context in which the music is created. The characteristics of the source material inform the development of techniques for resynthesis and transformation of environmental sounds. My synthesis methods make use of ecologically feasible time patterns and finite sound events. Thus, both materials and formal processes are closely related to the listener's experience within a specific sound environment. Given that the sonic environment and the listener are engaged in a process of mutual determination, ecologically based composition provides us with tools to shape the sounds that surround us and to change the way we perceive these sounds.

References

1. F.J. Varela, E. Thompson and E. Rosch, *The Embodied Mind: Cognitive Science and Human Experience* (Cambridge, MA: MIT Press, 1989).

2. C.F. Michaels and C. Carello, *Direct Perception* (Englewood Cliffs, NJ: Prentice-Hall, 1981).

3. L.A. Hiller and L.M. Isaacson, *Experimental Music: Composition with an Electronic Computer* (New York: McGraw-Hill, 1959).

4. I. Xenakis, *Formalized Music* (Bloomington, IN: Indiana Univ. Press, 1971) p. 22.

5. A.S. Bregman, *Auditory Scene Analysis: The Perceptual Organization of Sound* (Cambridge, MA: MIT Press, 1990).

6. B.T. Tróccoli and D. Keller, *A série harmônica: interpretação inter-disciplinar—física, psico-acústica, histórica—e o processo audio-perceptivo*, technical report (in Portuguese) (Brasília, DF: Fundação de Apoio à Pesquisa do D.F, 1996).

7. A.C. North and D.J. Hargreaves, "Experimental Aesthetics and Everyday Music Listening," in D.J. Hargreaves and A.C. North, eds., *The Social Psychology of Music,* (New York: Oxford Univ. Press, 1997).

8. J. Attali, *Noise: The Political Economy of Music* (Minneapolis, MN: Univ. of Minnesota Press, 1985).

9. R.M. Schafer, *The Tuning of the World* (New York: Knopf, 1977).

10. B. Truax, "Composing with Time-Shifted Environmental Sound," *Leonardo Music Journal* **2** (1992) pp. 37–40.

11. H. Westerkamp, *Transformations,* empreintes DIGITALes Compact Disc (Montreal, 1996).

12. B. Truax, "Soundscape, Acoustic Communication and Environmental Sound Composition," *Contemporary Music Review* **15,** No. 1, 47–63 (1996).

13. J.J. Gibson, *The Senses Considered as Perceptual Systems* (Boston, MA: Houghton Mifflin, 1966).

14. W.H. Warren and R.R. Verbrugge, "Auditory Perception of Breaking and Bouncing Events: A Case Study in Ecological Acoustics," *Journal of Experimental Psychology: Human Perception and Performance* **10** (1984) pp. 704–712.

15. W.H. Warren, E.E. Kim and R. Husney, "The Way the Ball Bounces: Visual and Auditory Perception of Elasticity and Control of the Bounce Pass," *Perception* **16** (1987) pp. 309–336.

16. D.P.W. Ellis, *Prediction-Driven Computational Auditory Scene Analysis,* Ph.D. thesis (Cambridge, MA: MIT Press, 1996); see also Bregman [5].

17. Michaels and Carello [2] p. 9.

18. Michaels and Carello [2] p. 13.

19. D. Keller, *touch'n'go: Ecological Models in Composition*, master of fine arts thesis (Burnaby, BC: Simon Fraser University, 1999); <http://www.sfu.ca/sonic-studio/EcoModelsComposition/Title.html>.

20. P. Ru and S.A. Shamma, "Representation of Musical Timbre in the Auditory Cortex," *Journal of New Music Research* **26** (1997) pp. 154–169.

21. R. Aiello, ed., *Musical Perceptions* (New York: Oxford Univ. Press, 1994).

22. J.A.S. Kelso, *Dynamic Patterns: The Self-Organization of Brain and Behavior* (Cambridge, MA: MIT Press, 1995).

23. North and Hargreaves [7].

24. Truax [12].

25. Bregman [5]; S. Handel, "Timbre Perception and Auditory Object Identification," in B.C.J. Moore, ed., *Hearing* (New York: Academic Press, 1995); S. McAdams, "Recognition of Sound Sources and Events," in S. McAdams and E. Bigand, eds., *Thinking in Sound* (Oxford: Oxford Univ. Press, 1993) pp. 146–198; D.W. Massaro and N. Cowan, "Information Processing Models: Microscopes of the Mind," *Annual Review of Psychology* **44**, 383–425 (1993).

26. Warren et al. [15].

27. McAdams [25]; C.L. Krumhansl, *Cognitive Foundations of Musical Pitch* (New York: Oxford Univ. Press, 1990).

28. Keller [19].

29. J. Hernández, *El Gaucho, Martín Fierro*, Vol. 1 (Buenos Aires: Peuser, 1946).

30. J. Cortázar, *La Vuelta al día en ochenta mundos* (Madrid: Siglo XXI, 1967).

31. H.I.J.O.S. <http://www.hijos.org>.

32. Kelso [22]; G. Kampis, *Self-Modifying Systems in Biology and Cognitive Science* (Oxford: Pergamon Press, 1991).

33. Varela et al. [1].

34. Kampis [32]; J.L. Borges, *Ficciones,* in *Obras Completas*, Vol. 5 (Buenos Aires: Emecé, 1956).

35. K. Karplus and A. Strong, "Digital Synthesis of Plucked-String and Drum Timbres," *Computer Music Journal* **7,** No. 2, 43–55 (1983).

36. D. Keller and C. Rolfe, "The Corner Effect," *Proceedings of the XIIth Colloquium of Musical Informatics* (Gorizia, Italy, 1998); X. Rodet, "Time-Domain Formant Wave Function Synthesis," *Computer Music Journal* **8,** No. 3, 9–14 (1984); B. Truax, "Discovering Inner Complexity: Time Shifting and Transposition with a Real-Time Granulation Technique," *Computer Music Journal* **18**, No. 2, 8–48 (1994).

37. C. Roads, "Sound Transformation by Convolution," in C. Roads, S. T. Pope, A. Piccialli and G. De Poli, eds., *Musical Signal Processing* (Lisse: Swets & Zeitlinger, 1997) pp. 411–438.

38. D. Keller and B. Truax, "Ecologically Based Granular Synthesis," *Proceedings of the International Computer Music Conference* (Ann Arbor, MI: ICMA, 1998); <http://www.sfu.ca/~dkeller>.

39. Keller and Rolfe [36].

40. Rodet [36].

41. D. Keller, ". . . *soretes de punta,*" in *Compact Disc Harangue II,* earsay productions (Burnaby, BC, 1998); <http://www.earsay.com>.

42. Keller [19].

43. Truax [36].

44. Harmonic Functions is the company that manufactures the DM8 system. See C. Rolfe, *DM8 Automated Diffusion System* (Burnaby, BC: Harmonic Functions, 1996).

45. Keller and Rolfe [36].

46. Varela et al. [1].

47. Schafer [9].

Glossary

abstract music—music in which the sound organization strategies avoid extra-musical references. Most "serious" European and North American music falls within this category.

ecological models—algorithmic tools used for the resynthesis of everyday sounds.

ecological psychology—the study of perceptual processes from a systemic perspective. Perception is understood as an adaptive process that transforms both the perceiver and the environment.

ecological validity—a set of experimentally based principles that define parametric constraints for sound resynthesis models and sonic organization strategies.

formants—groups of partials that form a spectral peak. Vowel sounds are characterized by two or more formants produced by the resonances of the vocal track. FOF (formant wave function) synthesis simulates formants by using trains of pulses. The pulses are windowed sine waves; the characteristics of the formants depend on the shape of the window applied.

grain pools—several short sampled sounds that retain their natural attack and decay characteristics.

grains—sound quanta. Short windowed sounds with durations from a few milliseconds to several centiseconds.

granular—pertaining to the grain. Granular attack and decay occur within milliseconds, as opposed to the event's attack and decay, which can last several seconds. See grains.

granular phase synchronicity, or phase-controlled granulation—a technique developed by Keller and Rolfe (1998) [45] that uses the phase among grain streams as a synthesis parameter.

parsing (or segregation)—the process of separating sound events from the constant flow of auditory stimuli. From a compositional perspective, parsing is defined as the process of selecting sounds that fulfill ecological constraints.

pattern formation—refers to the emergence of higher-level forms or behaviors from the interaction of two or more systems. From a biological perspective, Varela et al. [46] define it as the process of mutual adaptation between the individual and the environment.

macro-time—level of sound structure composed of several events. Forms of organization at this level usually result from interactions among lower-level processes.

meso-time—level of sound structure ranging from a few grains (centiseconds) to several seconds. Most ecologically feasible events can be resynthesized by using meso-time patterns.

micro-time—level of sound structure lasting between a few nanoseconds to a few milliseconds.

soundscape—a term coined by composer R.M. Schafer [47] to describe the acoustic environment.

spectral—related to the spectrum of a sound, i.e. its frequency content.

time-patterns—temporal structures of sound events.

Manuscript received 1 March 2000.

Damián Keller was born in Buenos Aires, Argentina. Since 1997 he has been working on the ecological approach to composition. His works include tape pieces, music for theater, film and installations.